# Appendix C
# Development of Site-Specific Response Spectra Based on Statistical Analysis of Strong-Motion Recordings

## C-1. Description of the Approach

The general approach used for this method is described by Kimball (1983) and in the U.S. Nuclear Regulatory Commission's Standard Review Plan (USNRC 1990). This method consists of conducting statistical analysis of a suite of strong motion recordings within a distance range and from earthquakes having magnitudes similar to the design earthquake. Before the statistical analysis is conducted, these recordings are first adjusted or modified for differences in magnitude, distance, style of faulting, site conditions, and other factors (e.g., topographic effects) between the site-specific conditions and the conditions for the recordings. Typically, records are selected from sites having subsurface conditions similar to those of the project, in which case no modification is needed for differences in site conditions. The approach consists of the following steps:

*a. Selecting recordings.* Select a suite of recordings from earthquakes having magnitudes and within a distance range similar to the design earthquake.

*b. Modification to recordings.* Adjust or modify peak ground acceleration and response spectral values for differences in magnitude, distance, style of faulting, and other factors between the site-specific conditions and the conditions for the recordings. These modifications are made using attenuation relationships for peak ground acceleration and response spectral values.

*c. Statistical analysis.* Conduct statistical analysis of the adjusted/modified response spectra of the recordings to obtain site-specific response spectra.

## C-2. Example

This example illustrates the use of statistical analysis of strong motion recordings to develop site-specific response spectra representative of recordings on rock or rocklike material for a strike-slip earthquake of moment magnitude 6.5 at a closest source-to-site distance of 18 km. A total of six rock recordings (12 horizontal components) obtained during shallow-crustal earthquakes of moment magnitude 6.5 ± 0.25 and recorded in the distance range 15 to 25 km were selected. These records are listed in Table C-1 in terms of the earthquake name, date, type of faulting, magnitude, distance, the component directions, and the peak acceleration value for each record. In this database, four records were from thrust earthquakes and two records were from strike-slip earthquakes. Before the statistical analysis of these near-source records was conducted, they were scaled/adjusted, if necessary, to be compatible with conditions at the site; i.e., they were adjusted to a moment magnitude of 6.5, a source-to-site distance of 18 km, and strike-slip style of faulting. Described below are the various scaling factors used to modify the records for distance, magnitude, and style of faulting.

*a. Scaling factors for distance and magnitude.* The rock attenuation relationships of Sadigh, Egan, and Youngs (1986) were selected for scaling peak ground acceleration and response spectral values. The relationships for strike-slip faulting are summarized in Table C-2. Using the attenuation relationships given in Table C-2 for each record listed in Table C-1, scaling factors were derived for peak ground acceleration (PGA) and response spectral ordinates relative to a moment magnitude $M_W$ of 6.5 and a source-to-site distance $R$ of 18 km. For example, the scaling factors for PGA for the San Fernando

**Table C-1**
**Database for Statistical Analysis for Shallow Crustal Earthquake ($M_W$ 6.5, R = 18 km)**

| Earthquake | Date | RUPT | $M_W$ | $M_L$ | STAN | CLD | COMP | PGA |
|---|---|---|---|---|---|---|---|---|
| San Fernando, CA | 2/9/71 | Thrust | 6.6 | 6.4 | 126 | 24.2 | S69E | 0.200 |
| | | | | | | | S21W | 0.159 |
| | | | | | 127 | 23.5 | N21E | 0.147 |
| | | | | | | | N69W | 0.131 |
| | | | | | 128 | 20.3 | N21E | 0.374 |
| | | | | | | | N69W | 0.288 |
| | | | | | 141 | 17.4 | S00W | 0.188 |
| | | | | | | | S00W | 0.180 |
| Imperial Valley (M) | 10/15/79 | Strike Slip | 6.5 | 6.6 | 6604 | 23.5 | N57W | 0.157 |
| | | | | | | | S33E | 0.166 |
| Morgan Hill | 4/24/84 | Strike Slip | 6.2 | 6.2 | 47379 | 16.2 | N40W | 0.100 |
| | | | | | | | S50W | 0.073 |

Note: RUPT = type of faulting
$M_W$ = moment magnitude
$M_L$ = local magnitude
STAN = station number
CLD = closest distance (km)
COMP = component
PGA = peak ground acceleration (g)

earthquake ($M_W$ = 6.6) record at Station 126 ($R$ = 24.2 km) and for the Morgan Hill earthquake ($M_W$ = 6.2) record at Station 47379 ($R$ = 16.2 km) were obtained as follows:

(1) For San Fernando earthquake record at Station 126:

$$\text{PGA scaling factor} = \frac{\text{PGA } (M_W \text{ 6.5, R = 18 km})}{\text{PGA } (M_W \text{ 6.6, R = 24.2 km})}$$

$$= \frac{0.191 \text{ g}}{0.147 \text{ g}} = 1.30$$

(2) For Morgan Hill earthquake record at Station 47379:

$$\text{PGA scaling factor} = \frac{\text{PGA } (M_W \text{ 6.5, R = 18 km})}{\text{PGA } (M_W \text{ 6.2, R = 16.2 km})}$$

$$= \frac{0.191 \text{ g}}{0.173 \text{ g}} = 1.10$$

Scaling factors for PGA for other records listed in Table C-1 were obtained in the same manner. Similarly, the attenuation relationships for response spectral velocity given in Table C-2 were used to derive spectrum scaling factors for various periods for each record.

**Table C-2**
**Values of Coefficients for the Selected Attenuation Relationship for Shallow Crustal Events, Horizontal Peak Ground Acceleration, and Pseudo-Relative Spectral Velocities (Rock Relationships by Sadigh, Egan, and Youngs 1986)**

| Ground Motion Parameter *Y* | Period sec | Coefficient | | | | $\sigma_Y$ |
|---|---|---|---|---|---|---|
| | | $C_1$ | $C_2$ | $C_3$ | $C_4$ | |
| PGA | --- | -1.406 | 0 | 1.353[a]<br>0.579[b] | 0.406[a]<br>0.537[b] | 1.26 - 0.14$M$[a]<br>0.35[b] |
| PSRV | 0.1 | 2.059 | 0.007 | 1.353[a]<br>0.579[b] | 0.406[a]<br>0.537[b] | 1.332 - 0.148$M$[a]<br>0.37[b] |
| PSRV | 0.2 | 2.961 | -0.008 | 1.353[a]<br>0.579[b] | 0.406[a]<br>0.537[b] | 1.453 - 0.162$M$[a]<br>0.40[b] |
| PSRV | 0.3 | 3.303 | -0.018 | 1.353[a]<br>0.579[b] | 0.406[a]<br>0.537[b] | 1.486 - 0.164$M$[a]<br>0.42[b] |
| PSRV | 0.5 | 3.564 | -0.036 | 1.353[a]<br>0.579[b] | 0.406[a]<br>0.537[b] | 1.584 - 0.176$M$[a]<br>0.44[b] |
| PSRV | 1.0 | 3.674 | -0.065 | 1.353[a]<br>0.579[b] | 0.406[a]<br>0.537[b] | 1.62 - 0.18$M$[a]<br>0.45[b] |
| PSRV | 2.0 | 3.601 | -0.100 | 1.353[a]<br>0.579[b] | 0.406[a]<br>0.537[b] | 1.62 - 0.18$M$[a]<br>0.45[b] |
| PSRV | 4.0 | 3.259 | -0.150 | 1.353[a]<br>0.579[b] | 0.406[a]<br>0.537[b] | 1.62 - 0.18$M$[a]<br>0.45[b] |

Note: Coefficients $C_1$ through $C_4$ for use in the relationship:
$\ln Y = C_1 + 1.1M + C_2\,(8.5 - M)^{2.5} - 2.05 \ln (R + C_3 \exp C_4 M)$ where $M$ is moment magnitude, and $R$ is closest distance to rupture surface in km.
$\sigma_Y$ = standard error of estimate of the relationship (the standard error in ln $Y$).
PGA = horizontal peak ground acceleration, g's.
PSRV = pseudo-relative spectral velocity (5% damping), cm/sec.

[a] Magnitude < 6.5
[b] Magnitude ≥ 6.5

*b. Scaling factors for style of faulting.* Quantification of the effect of style of faulting on PGA was based on published studies, analysis of soil and rock data sets, and numerical modeling results (Table C-3). On the basis of these analyses, a factor of 0.833 (or 1/1.2) was selected to scale recordings from a thrust faulting mechanism to a strike-slip faulting mechanism.

*c. Results.* The response spectra for each record in Table C-1 were adjusted (on a relative basis) to a target moment magnitude of 6.5 and a target distance of 18 km using appropriate magnitude and distance scaling relationships (i.e., using the selected attenuation relationships in Table C-2). Also, the response spectra of the four recordings from thrust earthquakes were adjusted (using a factor of 0.833) to a strike-slip style of faulting mechanism. Subsequently, a statistical analysis of this adjusted response spectral data set was performed on the logarithm of spectral pseudo-relative velocity (PSRV). The results of the analysis are shown in Figure C-1 in terms of the median (50th percentile) and median plus one standard deviation (84th percentile) of the fitted log-normal distribution for a damping value of 5 percent. It is noted that before such spectra are designated as design spectra, it would be appropriate to smooth the spectral peaks and valleys.

**Table C-3**
**Effect of Style of Faulting on Peak Ground Acceleration**

| **Empirical Relationships** | **Ratio of PGA for Thrust Faulting to PGA for Strike-Slip Faulting** |
|---|---|
| Campbell (1981) | 1.17 - 1.28 |
| Campbell (1987) | 1.38 - 1.40 |
| Campbell (1990) | 1.24 |
| Joyner and Boore (1996) | 1.25 |
| Sadigh, Egan, and Youngs (1986) | 1.20 |
| Long Term Seismic Program (Pacific Gas and Electric Company (PG&E) 1988) | 1.22 - 1.27 |
| Numerical Simulations | |
| Boore and Boatwright (1984) | 1.14 - 1.28 |
| Long Term Seismic Program (PG&E 1988) | 1.16 |
| Selected for the Example Study | 1.2 |

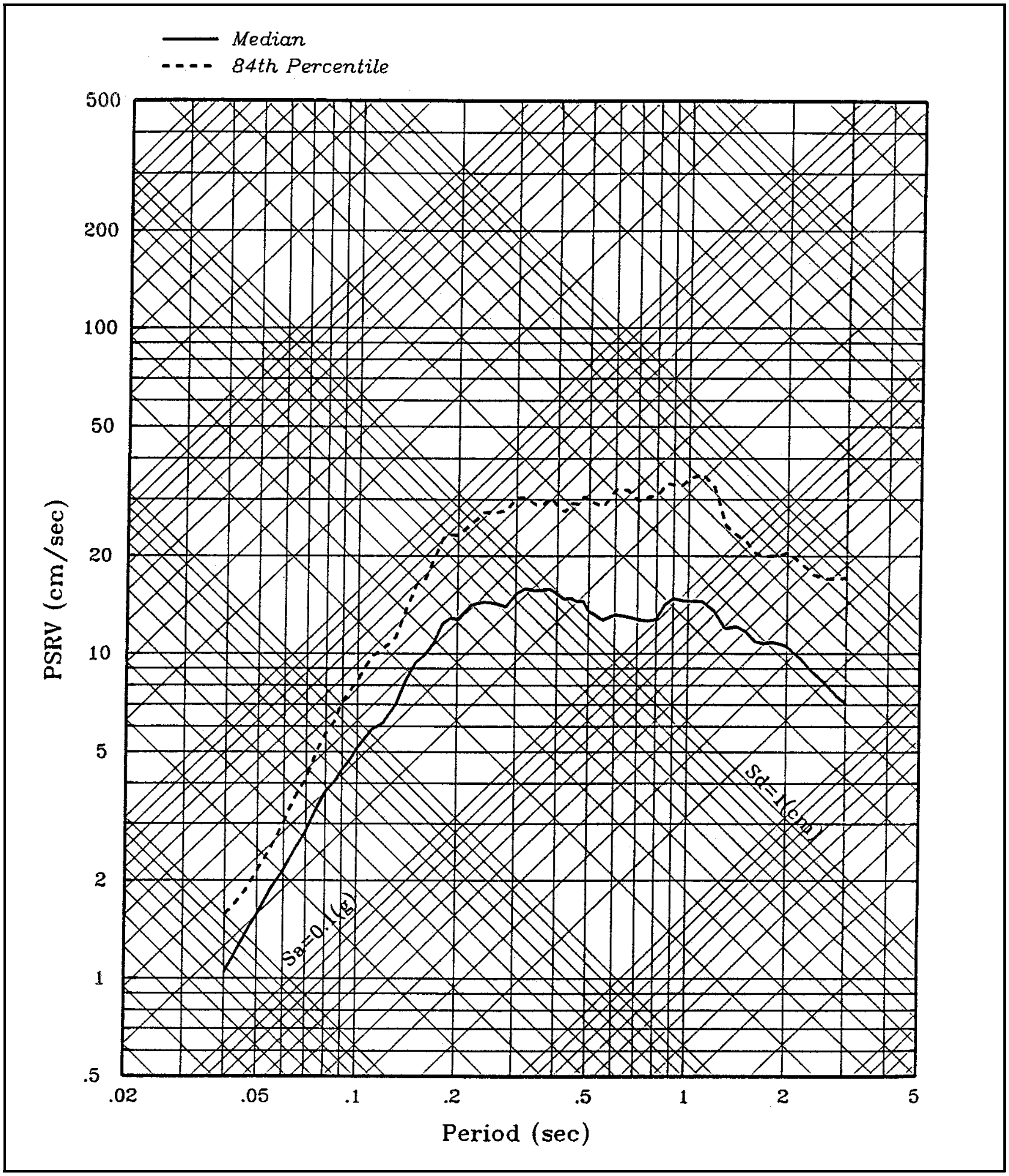


**Figure C-1. Median and 84th percentile spectra (5 percent damping) for a magnitude 6.5 strike-slip earthquake at 18 km based on statistics of adjusted rock recordings**